Sveriges lantbruksuniversitet
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Photo Gösta Hedberg

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Rapport 057
ISSN 1654-9406
Uppsala 2013

SLU, Sveriges lantbruksuniversitet
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ABSTRACT

Johansson, T. 2013. Discolored stems of 12-63-year-old European aspen (*Populus tremula* L.).

European aspen (*Populus tremula* L.) is an inherent species in Sweden and other Nordic countries. Products from aspen are timber, pulp wood, biofuel and veneer for furniture and matches.

Aspen is damaged by fungi, insects and wild habitat. Two main forms of rot are root rot (*Armillaria mellea* (Vahl.) Quel.) and stem rot or white heartwood rot (*Phellinus tremulae* (Bondartsev) Bondartsev & P.N. Borisov). But discolored wood is the most frequent form of changes in the aspen wood. In the report an overview of the factors causing discolored wood as well as the industrial use and quality of the end products is presented.

The study was made at eight locations in Sweden (Lat. 65° N. Long 20° E.; Lat. 64° N. Long 19° E.; Lat. 62° N. Long 15° E.; Lat. 60° N. Long 16° E.; Lat. 60° N. Long 17° E.; Lat. 58° N. Long 14° E.; Lat. 58° N. Long 12° E.; Lat. 57° N. Long 13° E. At each of the locations five stands were evaluated. In the stand ten aspens were sampled, totally 400 aspens. Stand parameters such as stem number, diameter at breast height, height, age, forest type and soil type was registered. The age, height and diameter at breast height of the felled stem was measured. The stem was cut in sections of 1 meter. Age and diameter of the sections was registered. The stem area was examined and the diameter of discolored wood or rot was registered.

The mean total age was 33±10 range 12-63 years, the mean height was 16.0±3.3 range 8.2-25.2 meter and the mean diameter at breast height was 172±28 range 81-340 mm. Most of the stands were growing on light clay till or sandy till.

Among the studied 400 aspens 91 % of the stems were discolored. At 1% of stem height 91 % was discolored and 56 % at 75 % of stem height. Part of the stem, 28 %, had a discolored radius of 21 range 5-51 mm at 25 % of stem height (≈ 4 meters). The discolored volume increased with increasing breast height diameter; 10.3 % at 153 mm and 19.1 % at 350 mm.

Equations describing discolored volume, %, by total stem volume were constructed. A table was also presented. These might be helpful for estimating the percentage of fresh wood in a stem.

Key word: *Armillaria mellea*; aspen; discolored wood; *Phellinus tremulae*; *Populus tremula*; root rot; soil type; white heartwood rot

SAMMANFATTNING

Aspen (*Populus tremula* L.) har ett brett utbredningsområde på den norra hemisfären och finns i större delen av Europa, Asien och Ryssland. I Norden är nordligaste utbredningen Lat. 71° N., Alt. 1 200 m.ö.h. Den växer i små bestånd, 0,1-0,5 hektar. Detta beror på att aspen är en klonbildare d.v.s. den föryngras genom rotskott vilket gör att den nya generationen asp har samma genetiska uppsättning som moderträden. Aspen växer på de flesta jordarter utom styv lera. Den växer dock långsamt och får en krokig kort stam på magra sandmarker. Den kräver rörligt grundvatten och friska till fuktiga marktyper för att ge maximal produktion. Etablering genom fröspridning och groning är sparsamt förekommande eftersom fröna är små och känsliga för konkurrens och uttorkning.

I Norden används aspen framför allt till produktion av timmer, massaved och biobränsle. Aspmassaved är numera en efterfrågad produkt för massaindustrin. I Sverige används de bästa kvaliteterna för tillverkning av tändstickor och bastulavar. Asptimmer används i Norge för tillverkning av tändstickor och konstruktion av mindre hus. Inomhuspanel av asp är en efterfrågad produkt i Norge.

Aspen angrips av olika arter av svampar, insekter och djur. Det är framför allt två svampar som skadar aspstammen: rotröta (*Armillaria mellea* (Vahl.) Quel.) och stamröta (*Phellinus tremulae* (Bondartsev) Bondartsev & P.N. Borisov). Rötfrekvensen ökar med ökad ålder. Ståndortsförhållanden och beståndsskötsel anses inverka på frekvensen röta. Aspkloner har olika resistens mot röta. Rotskotten kan angripas av rotröta. Utöver vednedbrytande svampar missfärgas aspens kärnved. Färgen varierar mellan grå-blå och brun. Missfärgningen beror på olika faktorer: bakteriell, kemisk eller fysiologisk. Det förekommer att veden blir missfärgad i anslutning till en död gren. I rapporten ges en kortfattad sammanfattning av hittillsvarande kunskaper kring missfärgning och de faktorer som är inblandade.

Studien omfattar åtta lokaler från Älvsbyn i norr till Tönnersjö i söder (Lat 65° N., Long. 20° Ö. till Lat. 57° N., Long. 13 Ö. På varje lokal valdes fem bestånd ut. Beståndens jordart och ståndort bestämdes. I beståndet valdes tio provträd ut. Totalt ingår 400 provträd av asp i studien. I beståndet registrerades stamantal, medeldiameter, medelhöjd jordart och skogstyp. Sedan fälldes de tio provträden. Ålder, höjd och brösthöjdsdiameter mättes in. Träden kapades

sedan i en-meters-sektioner. Ålder och diameter för varje sektion registrerades. Utbredningen av missfärgad ved eller i några fall rötskadad ved mättes in.

Totalåldern för bestånden var i medeltal 33±10 (12-63) år, medelhöjden 16,0 ±3,3 (8,2–25,2) meter och medeldiametern i brösthöjd 172±28 (81-340) mm. Huvuddelen av bestånden växte på lätt moränlera eller sandig morän.

Bland de 400 studerade aspstammarna var 91 % m missfärgade. På 1 % av trädhöjden var 91 % av samtliga stammar missfärgade och på 75 % av trädhöjden var 56 % missfärgade. Vid 25 % av trädhöjden (≈ 4 m) var den missfärgade radien i medeltal 21 (5-51) mm och 15 (5-33) mm vid 50 % av trädhöjden (≈ 8 m).

För att underlätta bedömningen av eventuell missfärgning av stammen har funktioner som beskriver den missfärgade volymen och den totala stamvolymen tagits fram. Vidare finns en tabell i rapporten där man kan studera brösthöjdsdiameterns inflytande på volymandelen missfärgad ved i stammen.

CONTENT

INTRODUCTION

During recent decades, there has been a general increase in interest in the management of broadleaved trees. This tendency has been evident in the Nordic countries and Europe as well as in Canada and the USA. There are several reasons for the increased interest:

(1) Damages and sustainable yield production in conifer stands increase. Acid rain, root rot (*Heterobasidion annosum* (Fr.) Bref.), wind break among others complicate the managing of conifer forests. Mixed stands of broadleaves and conifers or pure stands of broadleaf species make it possible to spread the risks to increase yield production.

(2) The pulp industry and saw mills demand more broadleaf logs as the pulp industry has developed methods to use a higher percentage of broadleaves in a mixed soft-and hardwood-pulp-process or only broadleaved pulpwood in the process. The demand of logs of broadleaves for sawing and later on for cabinet work has increased.

(3) As the discussion of biodiversity has increased the demand for methods for more stands with broadleaf species and their management have been stated.

(4) Economic realities make it necessary to use natural regeneration both by seed fall and by suckering and sprouting of broadleaves. The rapid growth of sprouts and suckers open new ways solving silvicultural and environmental efforts in the forestry.

European aspen (*Populus tremula* L.) cover the Nordic countries up to the most northern parts (Lat. 71° N Alt 1200 m a.s.l.) and is also found on most parts of Europe and Asia (Blumenthal, 1942). European aspen grows in stands on small areas (0.1 - 0.5 ha). In Sweden the standing volume for European aspen is 45.3 million m^3, which is 1.5 % of the total standing volume (Anon, 2012). The diameter distribution is 5.9 mill. m^3 for stems <150 mm, 11.9 for stems 150-249 and 27.6 for stems >250 mm. In North America two clones of the American species trembling aspen (*Populus tremuloides* Michx.) cover 10.1 and 43.3 ha respectively (Kemperman and Barnes, 1976). Aspens are spread to other areas mostly after a forest fire. Mostly an aspen stand consists of only one clone regenerated by suckers. European aspen produce most seeds at 40 to 50 years of age (Reim, 1930). The seeds are small and are spread 400 to 500 meters. An aspen tree could produce 54 million seeds weighing 29 kg (Reim, 1930). The tree species tolerates frost well. In general, the aspen are mixed with other species as Norway spruce (*Picea abies* (L.) Karst.), Scots pine, birches (*Betula pubescens* Ehrh. and *Betula pendula* Roth). Aspen has been studied as a potential producer of timber of different quality including manufacture of matches (Jørgensen, 1952; Tikka, 1954; Vadla, 1987). Aspen grows on areas with a wide spectrum of climate conditions and site qualities. The favourable conditions for growth are on moist fertile sites except heavy clay soils. From the results of Stoecheler's (1960) study, aspen growing on soils with 60 % mixed content of light and medium clay and silt soil have the highest yield production. On dry poor sites the growth rate is low and the stems are curved and bushy.

Zehngraff (1947) has analysed the relation of yields and rotations of trembling aspen to sites as follows:

- Good sites: Aspen reaches saw logs size at the rotation age of 55 ages. Yields of 400 m^3 ha^{-1} or more are attainable.
- Medium sites: The trees produce small logs and pulpwood at the rotation age of 45 years. Estimated maximum yields are about 300 (296) m^3 ha^{-1}.
- Poor sites: Aspen seldom reaches more than pulpwood size at the rotation age of about 30 years. Maximum yields may run up to 160 (161) m^3 ha^{-1}, but more often they are substantially less than 100 m^3 ha^{-1}. Much of the poor site aspen is of no commercial value at the present time. But as the demand for biofuel increases the aspen biomass could be of interest.

The wood quality of different broadleaf species is defined according to their properties including the color of the wood. For most species the wood color is uniform from the pith to the cambium. Darkly colored wood is normal in some species [e.g., elm (*Ulmus* sp.); oak (*Quercus* sp.); sweet chestnut (*Castania sativa* L.); black walnut (*Juglans regia* L.)].
Wood discoloration has been reported for some broadleaved species: poplars (Hofstra et al., 1999); European aspen (*Populus* tremula L.) (Børset and Haugberg (1960, Bakken, 1962, Vadla 1987); beech, (*Fagus sylvatica* L.) (Nečesany, 1956); wild cherry (*Prunus avium* L.) (Pryor, 1988); paper birch (*Betula papyrifera* Marsh.) (Drouin et al., 2009); silver birch (*Betula pendula* Roth) (Luostarinen and Verkasalo, 2000) and ash (*Fraxinus excelsior* L.) (Benic, 1954).

When describing discoloration found in broadleaf species, there are different names for the phenomenon: affected wood, discolored wood, stained wood, wetwood, wounded wood, black heart, red heart, black heartwood, false heartwood, pathological heartwood, red heartwood etc. (Jørgensen, 1952: Siegle, 1967: Shigo, 1967, 1973: Shigo and Larson, 1969: Shigo and Hillis, 1973: Basham, 1991 and Kerr, 1998). There is no common name that has been officially accepted in the terminology. Here discolored wood (DW) is used throughout the paper but, where quoted, the name as written in the referenced report is practiced. Information about different types of discoloration and species is presented among others by Hörnfeldt et al. (2010) who wrote an overview of DW in beech, birch and ash. Kerr (1998) reviewed the occurrence of black heart in ash in relation to management and the influence on timber price and Ward and Pong (1980) reported on the available information about wetwood in trees.

Wetwood is a type of discolored wood and appears in aspen and poplar but also in willow (*Salix* sp.) and fir (*Abies* sp.) (Hartley, 1961). It is the general name for discolored zones not associated with decay columns. Such zones are characterized by a high mineral and moisture content, by variable bacterial population, and by being impermeable to liquid. True heartwood in aspen stems, if it exits, is difficult to distinguish in stems. Therefore, DW with a light to dark grey color in aspen stems is easy to observe. There are no published reports or first-hand experience of the importance and extent of wetwood in aspen in Sweden. Below follows an overview of the main factors and experiences of this discolored wood, based on international scientific reports and knowledge. Wetwood is a type of heartwood that has high water content (Ward and Pong, 1980). The odour of fresh wetwood indicates anaerobic bacteria activity (Ward and Pong, 1980). According to Wallin (1954) bacteria was more frequent in wetwood (92.5% of total isolation) of balsam poplar than in sapwood (54.4%). In a review of discoloration in the wood of living and cut tree species, Bauch (1984) concluded that discoloration including wetwood is caused by physiological processes (environmentally initiated), biochemical and chemical reactions. Børset and Haugberg (1960) reported that discolored wood is a chemical reaction.

According to the presented overview of the literature, discoloration of the wood of broadleaf species is common. From a practical point of view, there are different opinions about the quality of discolored wood in stems. Although the discoloration caused by “wetwood” in aspen largely disappears when dried, the wood is brash and subject to splitting and cracking, and has reduced strength. Because the color fades, it is difficult to detect and cull out these affected zones early in the manufacturing process. Hiratsuka and Loman (1984) concluded, in a review of decay of aspen and balsam poplar in Alberta, that plywood production demands decay-free, high quality logs for veneer. DW reduces the veneer quality. To reduce the higher moisture content in poplar veneer logs to 5 %, it requires 15 % more time to dry than for spruce. Sachs et al. (1974) reported that wetwood took two to six times longer to dry than sapwood in order to reach a level of 6 % – 8 % moisture. A similar conclusion about the need for a longer drying period is reported by Boone (1990). Ward and Pong (1980) concluded in their overview that wetwood is a cause of losses of wood for the industry. The wood must be dried for 50 % longer than fresh wood. Dried board made of wetwood could crack more and develop other quality defects.

Besides discolored wood, aspen is infected by fungus, insects and wild habitat. Young aspen are infected by fungus tissues (*Venturia populina* (Vuill.) Fabric.), which cause leaf and shoot blights on the trees. Rust on leaves, mostly *Melampsora pinitorqua* Rostr., alternate between aspen and Scots pine (*Pinus sylvestris* L.) and/or Wild Rosemary (*Ledum palustre* L.) cause damages on leaves and decreases the growth. Infections by *Melampsora* causes severe shoot distortion and die-back in Scots pine. There are two types of rot, in roots and in stems. Root rot is common and is caused by Honey fungus as Shoestring Root Rot (*Armillaria mellea* (Vahl.) Quel.). Infected part in centrum of the base of an aspen stem dark brown colored with black segments directed to centrum of stem. Stem rot is caused among others by white heartwood rot (*Phellinus tremulae* (Bondartsev) Bondartsev & P.N. Borisov). The wood is spongy, yellowish in color, and the decayed wood contains a number of irregular concentric black zone lines. A brown stain is usually found on the outside perimeter of the decayed wood. The rot can occur throughout the length of the tree and often, in advanced stages, sapwood tissue is invaded.

The most serious damages are made by moose (*Alces alces* Lin.), deer (*Cervus elaphus* Lin.), rawdeer (*Capreolus capreolus capreolus* Lin.), hare (*Lepus capensis* Lin, *Lepus timidus* Lin.) and rabbit (*Oryctolagus cuniculus* Pallas) which browsing the young trees and gnaw the bark on 10-30-year-old aspens. Then the spores from fungus species infest the wood in the damage areas. The aspen wood will be discolored and later on the stem is damaged by rot, which causes economic losses for the owner as the timber quality is too bad for sale. Small aspens are grazed and the young trees decrease in yield as the leaders are lost and the tree must develop a new one.

AIM

The primary aim of this report is to present the frequency of discolored/rot infected wood for European aspen growing on different localities, Lat. 56-64° N. The secondary aim is to measure the distribution of the discoloured wood at every meter of the stem. The dependence of soil type on the distribution of discolored wood is also studied.

MATERIAL AND METHODS

Characteristics of studied stands

Aspen stands were identified throughout eight localities of Sweden, Figure 1. Ten trees per stand were cut. Most of the stands had been thinned once prior to the study and a smaller number had not been thinned at all but as a young stand cleaned. Before a stand was accepted for the study the stems were examined concerning damages caused by moose. The mean number of stems per ha was calculated based on the numbers of stems counted in five 100-m^2 plots, Table 1. Among the identified stands 40, ranging in age from 12 to 63 years, were used, Tables 2 and 3.

Each stands, most of which were 0.2-0.7 ha in size, was divided up into ten 100 m^2 plots. The plots were uniformly distributed on the stand area. On each of these plots one dominant (=coarsest tree) tree was chosen. These ten trees were then examined if they had an undamaged, straight stem without double leaders or a broken leader. Otherwise a new sample tree was chosen by the remaining aspens on the plot. Furthermore, aspens growing alone in large openings were excluded from consideration. Based on total age and dominant height of the sampled ten trees per stand, site index for the stand was estimated (Johansson, 1996).

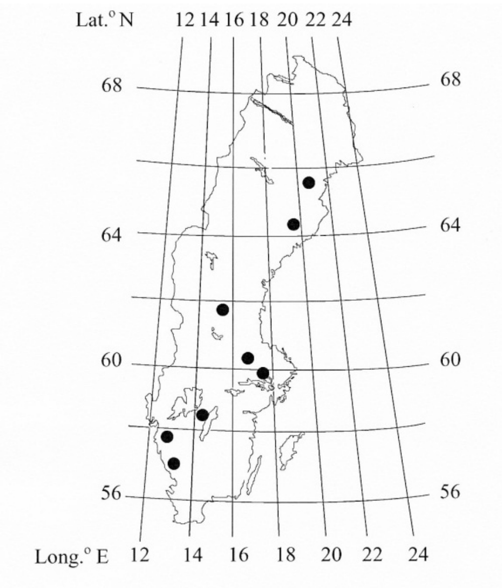

Figure 1. Map showing the eight locations of studied aspen stands.

Table 1. Number of stems ha^{-1} and double bark thickness, mm, for European aspen (*Populus tremula* L.) growing on eight localities.

Stand no.	No. stems ha^{-1}	DBH, mm, ob	Bark thickness, mm	No. stems ha^{-1}	DBH, mm, ob	Bark thickness, mm
	Älvsbyn			**Vindeln**		
1	2000	175±21	9.2±0.9	700	156±19	8.3±0.9
2	2800	130±16	7.3±0.7	1500	170±18	9.0±0.8
3	1700	173±23	9.3±1.2	1500	172±13	9.2±0.6
4	2000	129±16	7.4±0.5	300	184±23	9.7±0.9
5	2000	119±24	7.1±1.1	500	180±20	9.2±0.9
	Ljusdal			**Garpenberg**		
1	2000	148±33	8.0±1.3	2950	89-119	6.1±0.6
2	1900	140±21	7.7±0.9	2700	81-128	5.6±0.8
3	2100	151±28	8.3±1.2	2600	87-176	6.5±1.2
4	2000	119±15	7.0±0.7	1960	140-228	9.6±1.2
5	2150	149±23	8.1±1.0	1750	128-220	9.6±1.2
	Uppland			**Remningstorp**		
1	600	297±34	14.2±1.4	3600	197-240	11.2±0.9
2	1100	172±15	9.5±0.8	5400	127-179	8.1±0.6
3	1200	184±20	9.6±1.0	500	151-199	9.0±0.7
4	1200	186±25	9.7±1.3	600	81-128	6.5±0.7
5	1900	214±29	10.8±1.3	1400	179-270	11.1±1.0
	Östad			**Tönnersjöheden**		
1	1800	205±29	10.4±1.2	1200	134-214	9.0±1.3
2	1700	230±15	11.3±0.7	400	144-278	101±2.0
3	1100	218±17	10.7±0.9	1300	102-202	8.1±1.3
4	1500	215±17	10.9±0.6	600	159-259	10.6±1.4
5	500	131±24	7.5±1.0	900	120-210	8.5±1.1

The chosen aspens were then felled and they were cut as near the ground as possible (15-20 cm stump height). Stem length (m) was measured and diameter at breast height, dbh, (mm) was registered, Table 3. Thereafter, bark thickness was measured, Table 1. The stem was then cut in segments for stem analysis. Discs (3-5 cm thick) from the stem at following heights were cut: 0 (stump height), 100, 130, 200, 300, ...cm. Tree age on the discs was then determined by counting the annual rings. The ring width was also measured on the 1.3-m-disc for each aspen. The disc at ground level (0.1 m) was used for estimating total age.

On the disks the discolored wood area was cross calipered as the pattern was irregular. Estimation of total stem volume and volume of discolored wood in stems was made. The volume of the sections, 1 m, was calculated. The volumes of sections were calculated by multiplying the stem and discolored wood area on the middle of each section by 1 m and then add all volume sections.

Table 2. Main characteristics for stands of European aspen (P*opulus tremula* L.) growing at eight localities. five stands per location.

Stand	Lat., N.	Long. E.	Alt, m	Soil type	Forest type[1)]	SI, H_{40}, m	SI, min-max
	Älvsbyn						
1	65º 48'	20º 32'	135	Light clay till	1	14.0	13-15
2	65º 37'	21º 25'	75	Light clay till	1	23.5	22-26
3	65º 40'	21º 24'	135	Sandy till	2	16.6	14-19
4	65º 38'	21º 24'	150	Sandy till	1	18.9	16-21
5	65º 41'	20º 54'	105	Light clay till	1	19.1	17-21
	Vindeln						
1	64º 11'	19º 45'	175	Sandy till	1	23,2	21-26
2	64º 11'	19º 44'	175	Sandy till	1	15,8	15-16
3	64º 10'	19º 43'	115	Fine sand	1	15,0	13-18
4	64º 16'	19º 41'	225	Silty till	1	17,0	15-19
5	64º 16'	19º 41'	240	Silty till	1	17,0	16-18
	Ljusdal						
1	61º 53'	15º 24'	375	Sandy till	1	18.6	15-21
2	61º 53'	15º 24'	375	Sandy till	1	17.0	14-20
3	61º 53'	15º 24'	375	Sandy till	1	18.2	16-20
4	61º 53'	15º 24'	375	Sandy till	1	16.6	14-18
5	61º 53'	15º 24'	375	Sandy till	1	18.7	15-22
	Garpenberg						
1	60º ´13'	16º 32'	95	Light clay till	2	27.3	26-29
2	60º ´13'	16º 32'	100	Medium clay till	2	23.8	19-29
3	60º ´11'	16º 32'	65	Light clay till	3	21.1	18-25
4	60º ´22'	16º 03'	85	Light clay till	3	18.8	16-21
5	60º ´22'	16º 03'	85	Light clay till	3	19.4	18-21
	Uppland						
1	60º ´13'	17º23'	35	Heavy clay till	4	23.9	22-27
2	60º ´13'	17º24'	40	Light clay till	2	20.7	19-23
3	60º ´01'	17º43'	40	Medium clay till	3	21.2	19-24
4	59º ´52'	17º56'	30	Light clay till	2	20.9	17-28
5	59º ´54'	17º53'	20	Medium clay till	2	19.0	18-21
	Remningstorp						
1	58º ´22'	13º59'	125	Light clay till	3	19,5	18-21
2	58º ´23'	14º00'	120	Medium clay till	3	21,8	19-24
3	58º ´22'	14º00'	130	Light clay till	3	19,9	18-21
4	58º ´22'	14º08'	125	Sandy till	3	23,5	18-29
5	58º ´22'	13º36'	140	Sandy till	3	20.4	17-24
	Östad						
1	57º 57'	12º 22'	75	Sandy till	4	20.7	19-22
2	57º 37'	12º 22'	80	Sandy till	4	23.1	19-27
3	57º 58'	12º 26'	65	Light clay till	3	23.1	19-22
4	57º 58'	12º 26'	65	Light clay till	3	22.0	20-26
5	58º 00'	12º 27'	70	Light clay till	3	17.3	15-19
	Tönnersjöheden						
1	56º 43'	13º 08'	95	Sandy till	3	18.7	16-21
2	56º 35'	13º 05'	40	Light clay till	3	17.1	16-19
3	56º 43'	13º 09'	175	Sandy till	3	24.1	20-29
4	56º 46'	13º 09'	175	Sandy till	3	18.4	17-20
5	56º 43'	13º 08'	95	Sandy till	3	17.2	15-19

1) Hägglund and Lundmark (1982): 1 = Mesic darf-shrub; 2=Mesic grass type; 3=Mesic dwarf-shrub type with small herbs; 4=Mesic dwarf-shrub with tall herbs.

Registering of discolored wood

The distribution of DW on the disks was measured in laboratory. Four classes were identified: Uncolored wood, wet wood, solid brown/red wood, and soft brown/red wood (rotten wood), Figure 2. In practice there was difficult to identify the different groups. Therefore all types were registered as discolored wood. But sections with soft rot with or without holes were separated. The diameter (ob) of the stem disk and the discoloured part was registered in cross direction.

Figure 2. Classes of discolored wood in aspen stems

Soft brown wood (Rotten and with hole) | Solid brown wood | Wet wood

Soil analysis

The soil profile of each of the stands was analysed and the mineral soil type registered (Table 2). Soil was sampled from ground level down to just below plough level. On average, a mean texture for 0-30 cm depth was taken. Soil type was classified in the field, following the instructions provided by Atterberg in Ekström (1926), and the soils were classified as either sediments or tills. The soil sample (500 g) was then classified by particle-size in the laboratory. The particle-size distribution was determined by a mechanical method with sieves (English and German standard). Soil types were classified in sediments; gravel (20-2 mm), coarse sand (2-0.2 mm), fine sand (0.2-0.02 mm), silt (0.02-0.002 mm), clay (< 0.002 mm), tills; gravel, sandy, fine sandy and silty and organogenic types of soil; moor-land peat and moss peat. The soil samples did not contain only one particle-size but the most frequent size named the soil type with one or two prefix of other less frequent soil types. The clay content was estimated using the hydrometer method. The clay soils were then classified depending on the percentage clay as follows; light clay (13-29 %), medium clay (30-40 %) and heavy clay (41-60 %) and till clay soils (13-60%). There were only one stand growing on sediments (fine sand) and no stand growing on organogenic soil types. Only stands growing on tills were used in the study.

Table 3. Main characteristics for sample trees in stands of European aspen (*Populus tremula* L.) growing at eight localities. Five stands per location.

Stand	Total age, years		DBH, mm, ob		Height, m	
	mean ±SD	min-max	mean ±SD	min-max	mean ±SD	min-max
	Älvsbyn					
1	55±1	53-56	175±21	143-206	17.2±0.6	16.4–18.4
2	22±2	18-26	130±16	107-151	14.7±1.5	11.9–16.3
3	39±2	37-44	173±23	124-212	16.2±1.6	13.9–17.8
4	34±2	31-37	129±16	114-148	17.0±1.1	14.5–18.3
5	23±2	20-27	119±24	93-158	12.2±0.6	11.2–13.4
	Vindeln					
1	21±1	19-22	156±19	126-190	13.8±0.6	12.7–15.0
2	52±1	51-54	170±18	146-202	18.4±0.4	17.5–18.8
3	48±11	31-63	172±13	154-192	16.2±1.5	13.5–17.9
4	36±3	31-41	184±23	161-215	15.6±0.9	13.9–17.1
5	36±4	30-42	180±20	146-210	15.6±1.4	13,1–17.0
	Ljusdal					
1	27±4	24-37	148±33	98-200	13.8±0.6	11.9–15.6
2	29±2	24-31	140±21	100-170	18.4±0.4	11.7–17.0
3	30±2	28-34	151±28	121-198	16.2±1.5	13.8–16.8
4	30±2	27-33	119±15	90-140	15.6±0.9	12.7–14.6
5	31±2	28-34	149±23	101-184	15.6±1.4	12.5–17.5
	Garpenberg					
1	15±1	13-17	109±9	89-119	12.1±1.0	9.4–13.0
2	16±1	14-17	97±18	81-128	11.0±2.0	8.2–13.7
3	19±2	17-23	122±30	87-176	11.5±0.5	10.7–12.3
4	39±6	33-52	183±28	140-228	18.8±1.1	17.0–20.1
5	46±2	43-49	184±27	128-220	21.4±1.0	19.1–22.1
	Uppland					
1	39±3	34-43	297±34	235-340	23.6±0.9	22.6–25.2
2	31±2	27-34	172±15	153-208	16.9±1.0	15.5–18.5
3	28±3	26-33	184±20	156-221	16.2±1.6	13.4–18.4
4	32±5	26-42	186±25	157-237	16.9±1.1	15.6–18.6
5	45±4	39-52	214±29	173-262	20.6±0.4	20.0–21.3
	Remningstorp					
1	38±3	34-44	227±18	197-240	18.9±0.6	18.2–19.9
2	22±2	19-25	149±16	127-179	13.5±1.4	11.1–15.7
3	32±2	29-36	169±16	151-199	16.7±1.0	15.2–18.5
4	17±2	15-19	111±16	81-128	11.3±1.3	9.6–12.8
5	34±6	27-47	222±29	179-270	18.0±1.6	14.9–19.6
	Östad					
1	40±4	31-45	205±29	169-236	20,5±1.4	17.0–21.7
2	30±4	26-38	230±15	208-253	18.4±1.3	15.7– 9.6
3	35±2	32-38	218±17	197-261	17.8±0.6	17.0–19.0
4	36±3	30-40	215±17	186-246	20.4±0.7	19.0–21.5
5	31±3	26-35	131±24	110-194	14.1±0.6	13.6–15.7
	Tönnersjöheden					
1	31±2	27-34	172±27	134-214	15.4±1.0	14.1–17.1
2	27±3	22-31	201±53	144-278	12.6±0.7	11.5–13.8
3	17±4	12-23	153±30	102-202	11.8±0.6	10.7–12.7
4	51±3	43-61	212±32	159-259	21.5±0.7	20.3–22.3
5	30±2	28-33	163±26	120-210	14.0±0.9	12.4–15.1

RESULTS

The mean height of the dominant aspens was 16.0 ± 3.3 m (range, 8.2 - 25.2 m), Table 4. The tallest aspens occurred in southern and middle Sweden (Lat. 56-60° N). The mean total age of the trees examined was 33 ± 10 years (range, 12 - 63 years), Table 4. The tallest aspens occurred in southern and middle Sweden (Lat. 56-60° N.). The mean total age of the trees examined was 33±10 years (range 12-63 years) Table 4.

Table 4. Total age, years, age at breast height, years, diameter at breast height, mm, ob and height, m for stands of European aspen (*Populus tremula* L.) growing on eight localities.

Location	Total age, years		Brh age, years		DBH, mm, ob		Height, m	
no.	M ±SD	min-max	M ±SD	min-max	M ±SD	min-max	M ±SD	min-max
1	35±12	18–56	33±12	17-55	145 ± 31	93–212	15.4 ±2.2	11.2–18.4
2	39±12	19–63	35±12	18-58	172 ± 20	126–215	15.9 ±1.8	12.7–18.8
3	30±3	24–37	26±3	21-33	141 ± 27	90–228	14.2 ±1.5	11.7–17.5
4	27±13	13–52	25±13	12-49	140 ± 44	81–229	14.9 ±4.4	8.2–22.6
5	35±7	23–52	34±7	24-51	212 ± 51	152–340	18.8 ±3.0	13.4–25.2
6	29±9	15–47	29±8	17-44	176 ± 48	81–270	15.7 ±3.1	9.6–19.9
7	34±5	26–45	31±5	22-43	200 ± 41	110–261	18.2 ±2.5	13.6–21.7
8	31±12	12–61	30±11	10-59	189 ± 40	102–278	15.0 ±3.6	10.7–22.3
Mean±SD	33±10	12–63	30±10	10-59	172 ± 28	81–340	16.0±3.3	8.2–25.2

The mean diameter on bark at breast height was 172 ± 28 mm (range, 81 - 340 mm), Table 4. The double bark thickness averaged 9 ± 2 mm (range, 5 - 16 mm) and the mean number of stems per hectare was 1635 ± 991 (range 300 – 5400), Table 1.

Frequency discolored wood

Discolored wood was found in most of the studied aspen stems. All but two stems by all stem levels at location 2 were discolored, Table 5. At locations 4, 7 and 8 all stems were discolored. The lowest number of discolored stems was found at location 5, where 32 out of 50 stems were discolored.

In the stem section close to ground (0-1 m) 15 % (56 stems) of all studied stems soft rot wood. Most of the infected stems were growing on locations 5 (24 %), 6 (26 %) and 7 (36 %).

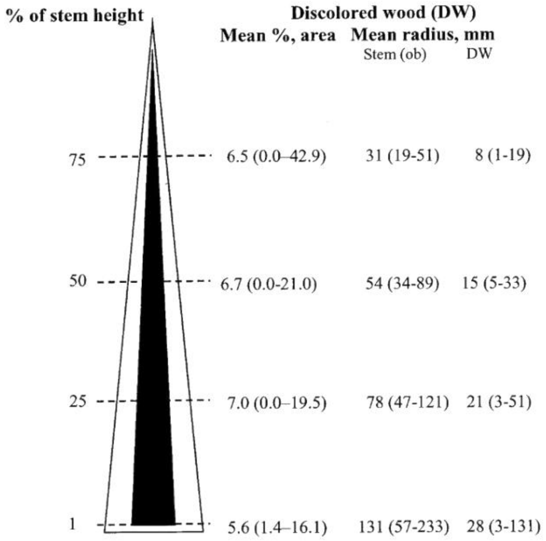

Figure 3. Mean (range) percentage area of discolored wood area by stem area at 1, 25, 50 and 75 % of tree height and mean (range) radius, mm, of stem and discolored wood (DW) in different sections

Table 5. Number of aspens with discolored stem at 1, 25, 50 and 75 % of stem height

Stand	Percentage of stem height							
no.	1 %	25 %	50 %	75 %	1 %	25 %	50 %	75 %
	(1) Älvsbyn				**(5) Uppland**			
1	7	4	1	6	10	10	6	5
2	10	10	10	10	6	1	7	0
3	8	7	7	5	6	1	0	0
4	9	9	8	4	6	2	4	2
5	5	6	5	6	4	0	0	0
Total	**39**	**36**	**31**	**31**	**32**	**14**	**17**	**7**
	(2) Vindeln				**(6) Remningstorp**			
1	10	10	10	10	10	9	9	8
2	10	10	10	10	9	6	6	4
3	8	10	10	10	9	6	3	3
4	10	10	10	10	10	9	10	6
5	10	10	10	10	10	9	8	3
Total	**48**	**50**	**50**	**50**	**48**	**39**	**36**	**24**
	(3) Ljusdal				**(7) Östad**			
1	8	10	8	5	10	5	3	0
2	10	9	10	3	10	8	8	4
3	10	10	10	8	10	9	8	5
4	9	9	8	4	10	8	10	6
5	9	8	8	6	10	10	9	7
Total	**46**	**46**	**44**	**26**	**50**	**40**	**38**	**22**
	(4) Garpenberg				**(8) Tönnersjöheden**			
1	10	10	9	6	10	10	10	7
2	10	10	10	8	10	10	10	8
3	10	10	10	6	10	10	9	6
4	10	9	6	8	10	8	6	4
5	10	10	9	10	10	8	6	3
Total	**50**	**49**	**44**	**38**	**50**	**46**	**41**	**28**

At 1 % of stem height all stems were discolored in locations 4, 7 and 8. At 1 % of stem height 91 % of sampled aspens was discolored and 56 % at 75 %, Table 6. There were small differences by stem height sections (1-75 %) of percentage discolored area by stem area, 5.6-7.0 %. The discolored part of stem radius was 21 (3-51) mm at 25 % stem height (≈4 m) and 15 (5-33) mm at 50 % (≈8 m), Figure 3.

Table 6. Percentage stems with discolored wood (DW) on different stem height (%)

1 %	25 %	50 %	75 %
90.7	80.2	77.7	56.0

Discolored wood volume in aspen stems

Stem volume and discolored volume of aspen trees was estimated by summarizing volume of stem sections (1 m), Figure 4. The mean stem volume was 0.18±0.01 (0.05-0.65) m^3 and the discolored volume 0.02±0.002 (0.001-0.1) m^3. The mean percentage discolored volume by stem volume was 10.23±0.47 (0.94-19.74) %., Table 7.

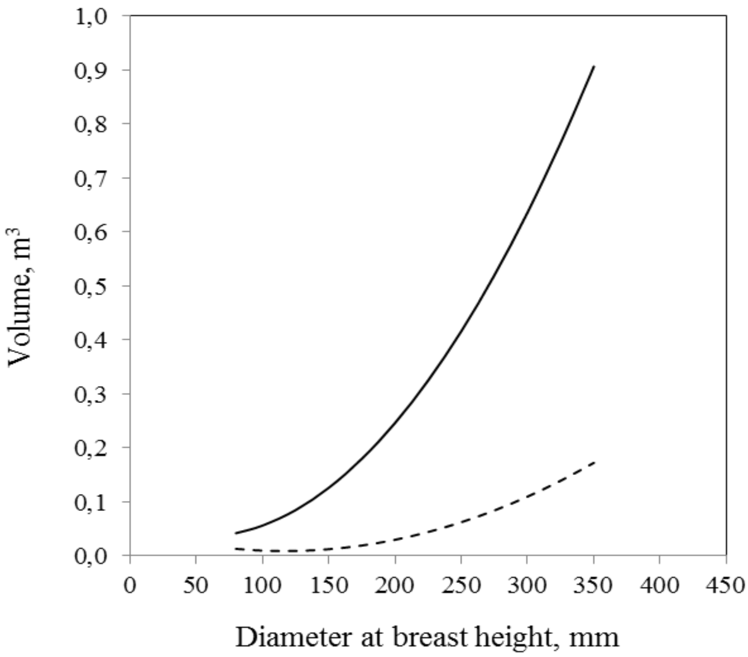

Figure 4. Total volume (—) and volume of discolored wood (- -) in aspen stems

Table 7. Percentage discolored wood volume (DWv) by total volume, %

	Diameter at breast height, mm				
	150	200	250	300	350
% DWv by total volume	10.3	12.2	15.1	17.3	19.1

DISCUSSION

Most of the stands (9 out of 15) in locations 1-3 (Lat. 61-66° N.) were growing on sandy till soils, cf. Table 1. The slower growing aspen on sandy till soils might partly depend upon the geographical localisation and soil type. Stands in the southernmost location 8 (Lat. 56° N.) were growing on sandy till with slower growth than stands in locations 6 and 7.

Discolored wood

Identification of type of DW is difficult as sometimes there is a mixture of two main fungi species and wet wood in the stems.

There are two frequent fungi species:

- White heartwood rot (*Phellinus tremulae* (Bondartsev) Bondartsev & P.N. Borisov), which cause a soft brownish wood at centre of the stem area, mostly with a violet circle (1-3 cm width) around the discolored wood. According to Eklund and Wennmark (1925) the stem rot could be found up to the green crown level of the aspen. In some cases the rot could be found in roots but only ≤ 0.5 m from the stump. Stem rot is not spread to suckers.
- Honey mushroom (*Armillaria mellea* (Vahl.) Quel.) causes a brown-black wood in centre with black bands out to periphery. Honey mushroom could be found up to 1 meter in the stem. In roots the rot could be found in a radius of 1.5 to 2 m from the stump. The infection of fungi starts in roots, which have been damage. Then the root rot is spread up in the stem, 0.5-1 meter.

Wet wood is a type of discolored wood:

- Basham (1961) reported discolored wood (80 %) in most (young and old) of studied trembling aspen stands.

  He found two different tint of color for wet wood:

  - Light brown-dark or grey brown
  - Mainly blotchy with yellow, brown and green tints

As there are difficulties to identify the discolored wood type the present study is based on uncolored and discolored solid wood without dividing them into different groups. The sections with soft rot with and without holes were presented in a special group.

Frequency discolored wood

In the present study 91 % of the studied aspen stands were discolored at 1 % of stem height and 56 % at 75 % of stem height. The mean diameter of discolored wood at 25 % of stem height (4 m) was 42 mm (total diameter = 156 mm) and at 50 % (8 m) 30 mm and 108 mm respectively. Vadla (1987) reported 82 % discolored stems by 254 stems. In another Norwegian study 71 % of 164 European aspen stems were discolored at breast height (Vadla, 1999). In the latter study the variation of discolored wood in stands was 40 to 100 %. In the present study 15 % of all stands had soft rot ranging 0.2 to 0.5 m in the stem.

Even young aspens, 20-25 years old, are infected by rot. In a study by Eklund and Wennmark (1925) 70 % of stems in a 25-year-old aspen stand were infected by rot with a diameter of 1-3 cm. In the present study 14 stands by 50 stands are younger than 30 years. Most of the stems, 8-10, were discolored at 1, 25 and 50 % of stem height. In a study on European aspen growing on forest land Eklund and Wennmark (1925) found that the distribution of rot increased by lack of management. They reported 23.3 % infected aspens in sites without management (e.g. cleaning and thinning). In a stand light thinned for 10 years ago the rot frequency was 6 % and in stands with repeated thinnings the rot frequency was 3.2 %. In the present study there was not an apparent correlation between dense stands and discolored wood frequency. Some young dense stands had low frequency and stands with low density (500 stems ha^{-1}) had 100 % DW. However it is important to manage the aspen stand for high growth, avoiding decays and for a a good wood quality. Perala (1978) recommend a first thinning when the “best” stems should be left even if they are in clumps close to each other. In the final thinning regular spaced cutting should be done avoiding damage on crop stems. As the aspen stems are sensitive for damage thinning should be done during dormant season. Then the bark does not slip as easily as in spring and summer.

In the present study the distribution and percentage discolored wood area depending on stem height differ in a small degree (5.6-7.0 %). Percentage discolored wood area in poplar stems was higher, 26 %, at 1 and 10 % of stem height than at 70 % of stem height, 7.5 % (Johansson and Hjelm, 2012). The mean percentage discolored aspen volume in the present study was 10.23 % with a large variation of 0.94 to 19.74 %. In a Norwegian study of 254 European aspen stems 49.5 % of the stem number had a discolored volume of <5 % (Vadla, 1987). In a study located in Ontario of two sites of trembling aspen the percentage DW was 3.89-10.25 and 3.16-29.12 % respectively (Kemperman et al., 1978). They found both discolored wood and advanced butt rot.

The percentage DW volume was 1.9 %. Davidson et al. (1959) studied 976 trembling aspens growing on 35 plots in Colorado. The studied stands were divided in three sites. The percentage DW differs depending on aspen age, Table 8:

Tree age, years	% discolored wood	Tree age, years	% discolored wood
Site no. 1			
41-86	0.8-5.8	114-170	1.9-17.3
Site no. 2			
55-83	0,7-8.0	107-153	0,1-23.1
Site no. 3			
53-66	1.8-7.5	104-131	16.2-24.6

Table 8. Percentage DW in trembling aspens (Davidson et al. 1959)

Frequency of discolored wood on sites

The frequency discolored (decayed) aspen stems is higher on poor than rich sites (Mathiensen, 1949). The distribution and frequency of rot in European aspen stems has been studied by Blumenthal (1942). He found that poor forest type had greater distribution and frequency of rot than rich forest type. In the study of Eklund and Wennmark (1925) the percentage rot in aspen stems increase with decreasing growth capacity. The frequency rot, especially root rot, is higher on dry sandy sites than on other sites (Basham, 1958). The status of soil moisture did not have an important influence on defect in aspen stems. In a study by Davidson et al. (1959) young trembling aspen stands had a low frequency rot and older stands had a higher frequency. Smith and Jackson (1927) and Riley (1952) could not find any correlation between rot frequency and site fertility. Wall (1969; 1971) concluded that highly significant differences have been found between clones in percentage decay and volume of decay (Kemperman et al., 1976b). About 38 % of variation in tree volume and 24 % of variation in average decayed volume in studied stands might be explained by genetic differences between clones (Kemperman et al., 1978).

Discolored wood in suckers

Suckers from cut mature aspen stands, which were infected by root rot were not infected (Eklund and Wennmark, 1925). In a Finnish study of aspen suckers developed after clear cutting of rot infected aspen, 93 of studied 15-18-year-old suckers were infected (Heikinheimo, 1915). In a study of 24 trembling aspen stands of suckers in areas cut for 15 to 20 years ago in Ontario the suckers were discolored (Smith, 1973). In 5-year-old stems of suckers 75 % some light-dark-brown stain and all of 15-20-year-old stems were discolored. Kemperman et al. (1976b) found discolored wood in 96 % of sampled 25-year-old sucker of trembling aspens.

CONCLUSIONS

This report focus on the frequency of discolored wood in European aspen stems. Few studies on this phenomenon for European aspen have been reported before. Among the studied 400 aspen stems 91 % were discolored. At 1 % of stem height 91 % were discolored and 56 % at 75 %. The mean percentage discolored stem area differed in a small degree depending on stem level and the radius of discolored wood distribution at different stem level range between 40 and 50 %. The percentage discolored wood volume in stems increased with increasing breast height diameter, 10.3 % at 150 mm and 19.1 % at 350 mm.

Discolored aspens could be used as board if there are no rot. As the sapwood radius part (40-50 %) of the stem diameter is free from discolored wood this part could be used as a high quality of board (sauna panels etc.). Today aspen logs which are discolored may not be used for making matches even if sapwood is free from discoloration. Discolored aspen as biomass for bioenergy purpose is acceptable by the heating company.

It is important to manage the aspen stands as the managed stand will grow faster and mostly be free of rot as the trees could be cut early, 50 years of age, instead of 70-80 years. All management should be done during winter time as the bark is sensitive for damages during spring and summer period. The first thinning should be made in young stands, 15-25 years. The most valuable trees e.g. undamaged and fast growing even growing in clumps should be left as crop stems. At next thinning, 30-35 years of age, the stem number should be reduced to 500-700 per hectare. Final cut should be done at 50 years of age.

However mostly aspen is mixed with Norway spruce. An ambitious management with thinnings of especially aspens with reducing the stem number at least in two stage: at 15-20 years of age the number of aspen should be 1000 to 1500 stems ha^{-1} depending on the density of Norway spruce: at 30 years of age 500 aspen stems ha^{-1} should be left and the stem number of Norway spruce should be 1500 to 2000.

A potential risk for causing rot in aspen stems is the gnawing on aspen bark by wild habitat (moose and deer). However the frequency of damage is based on the number of animals, which of several occasions cannot be drastically reduced. A mixed stand of aspen and Norway spruce may decrease the frequency of attacks.

ACKNOWLEDGEMENTS

J.-E. Lundh and K. Gustafsson measured and cut the stands. H. Johansson, M. Johansson, B. Forsmark, E. Hurtig and B. Fredriksson carried out the tree-ring analysis.
All of the above persons are gratefully acknowledged.

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